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(54) DEVICE AND METHOD FOR MEASURING THE POSITION OF A MOBILE PART

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This patent is subject to a terminal disclaimer.

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G01R 19/20 (2006.01)

(52) **U.S. Cl.** .... **324/253**; 324/117 R; 335/297

(58) **Field of Classification Search** 324/207.13, 324/207.15, 207.16, 207.24, 207.25, 253
See application file for complete search history.

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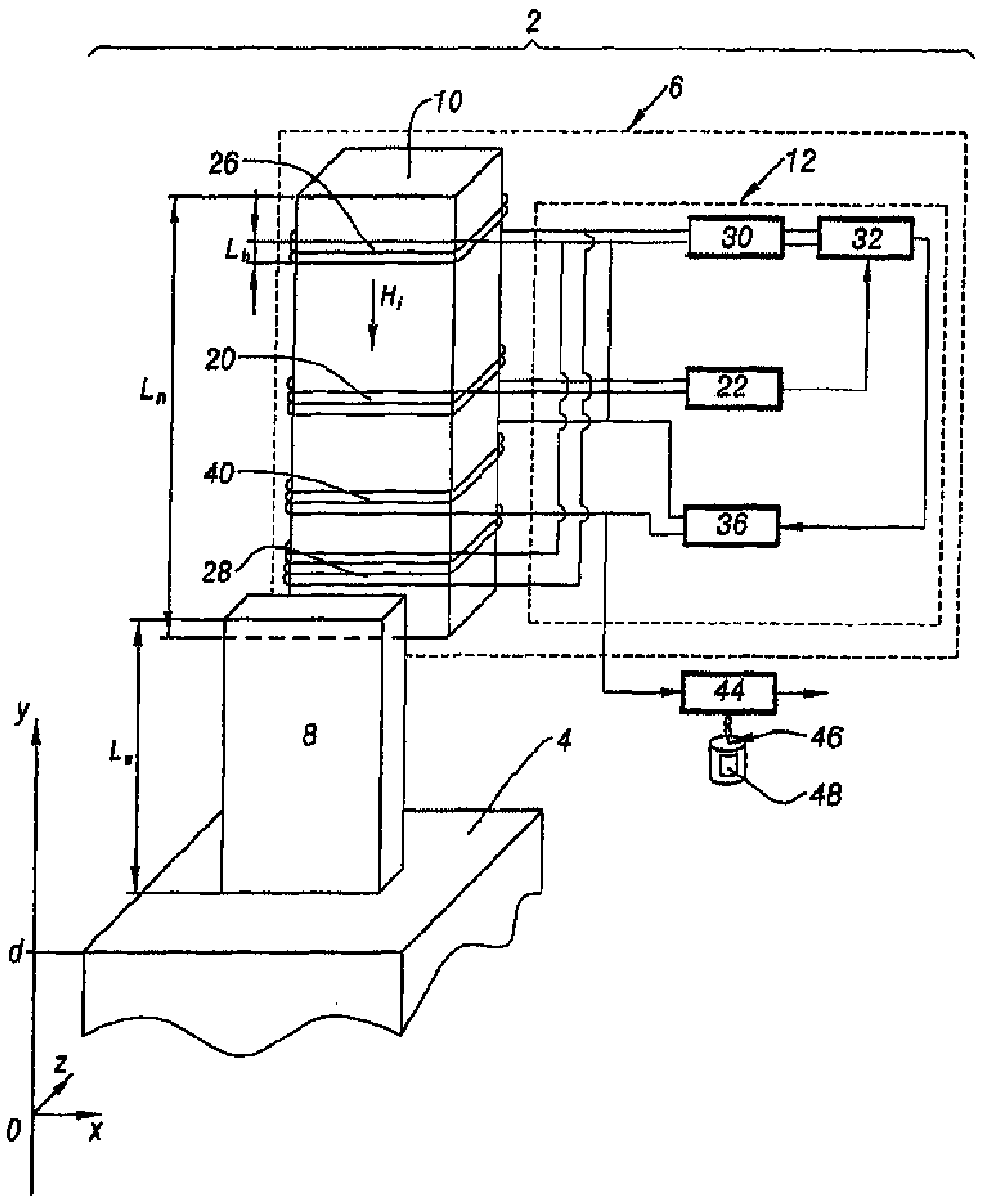
(57) ABSTRACT

A device for measuring the position of a mobile part (**4**), includes: at least one magnetic node (**10**) capable of modulating the amplitude of an excitation magnetic field according to the amplitude of a magnetic field to be measured, the magnetic node having a magnetic cycle for magnetic induction that depends on the hysteresis-free magnetic field in an operation range [H_{min}; H_{max}], and in which the magnetic cycle of the magnetic node (**10**) is characterised in that the absolute value of the third derivative of the magnetic induction relative to the magnetic field is maximal for a zero magnetic field.

14 Claims, 5 Drawing Sheets



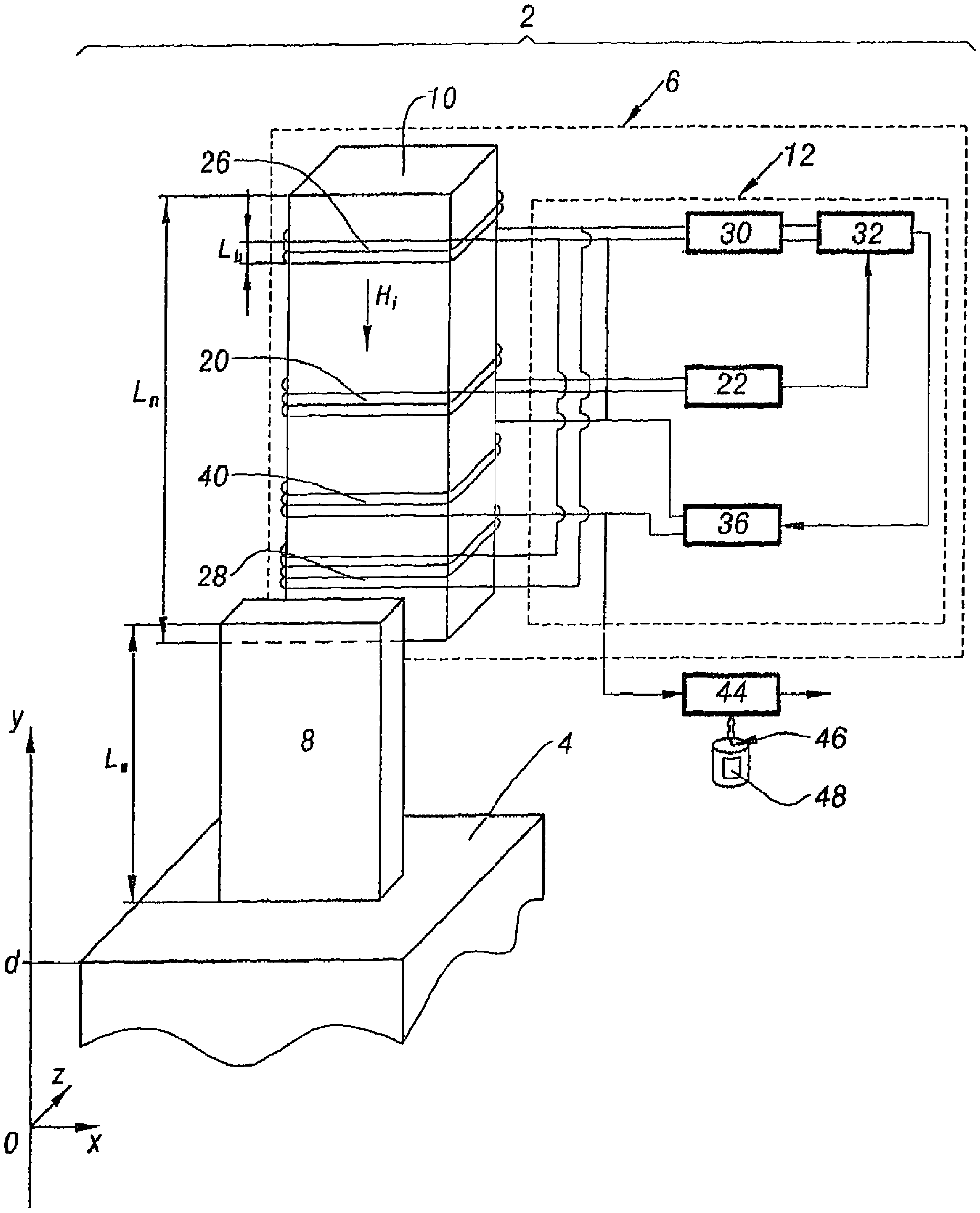


Fig. 1

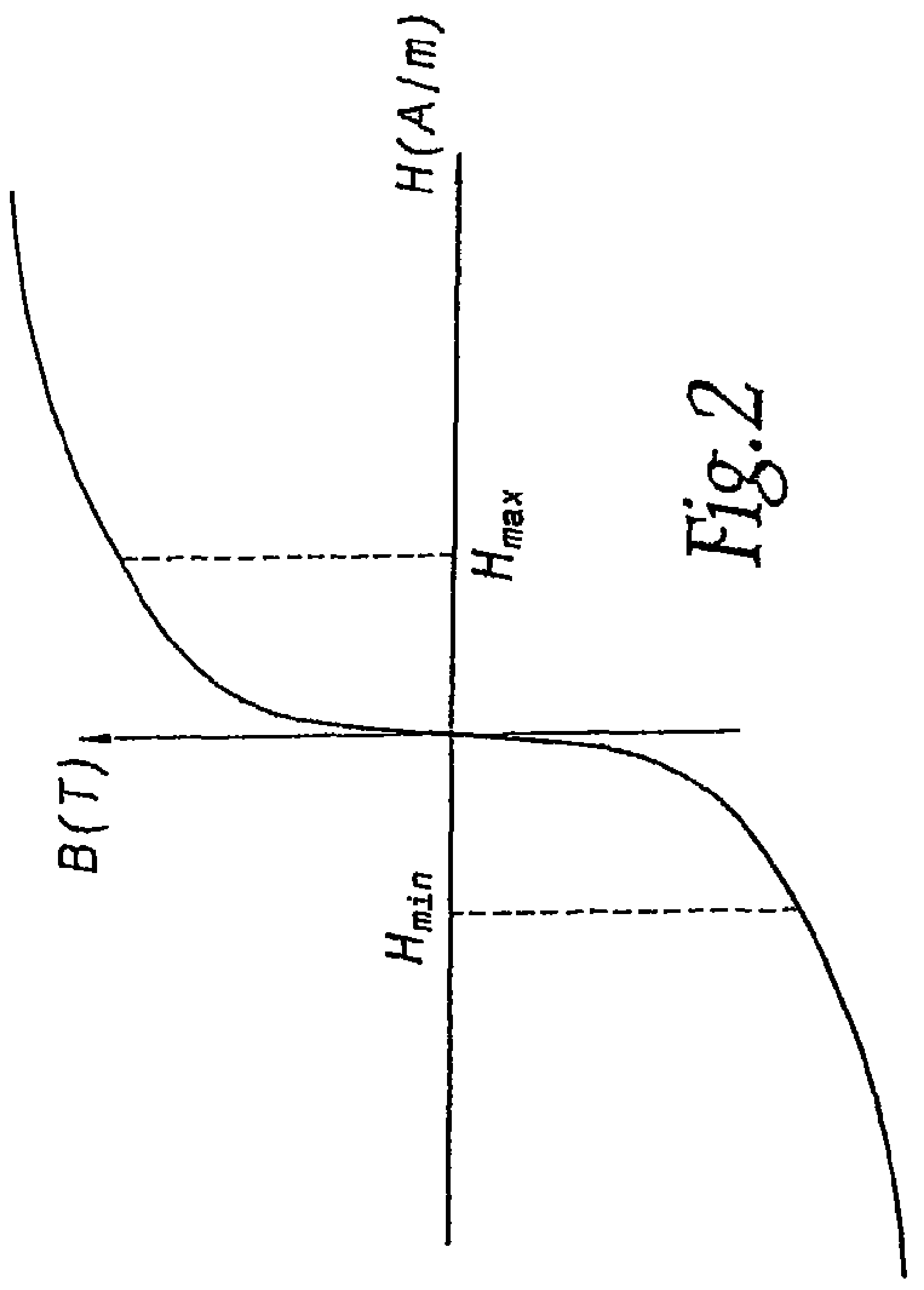


Fig.2

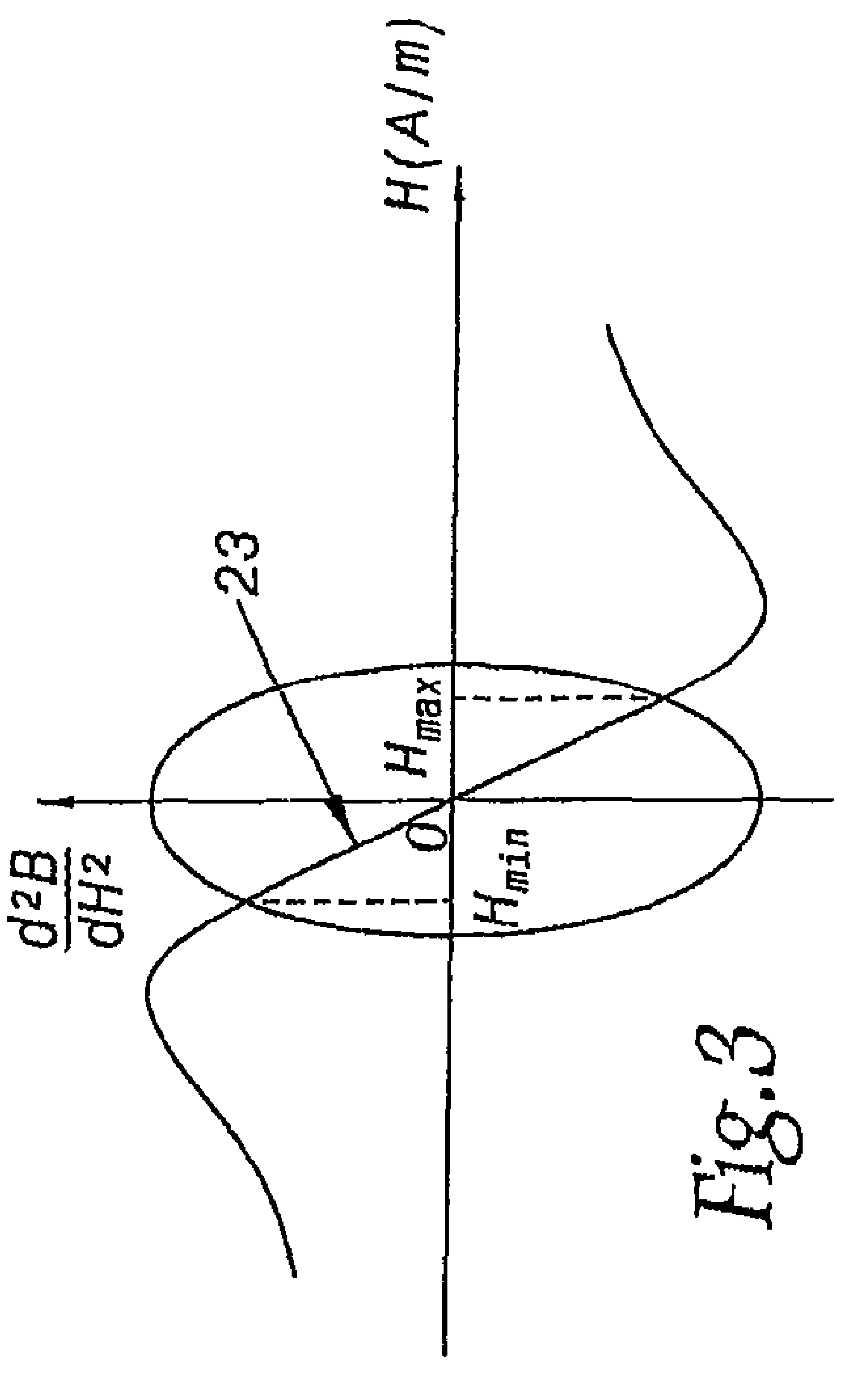


Fig.3

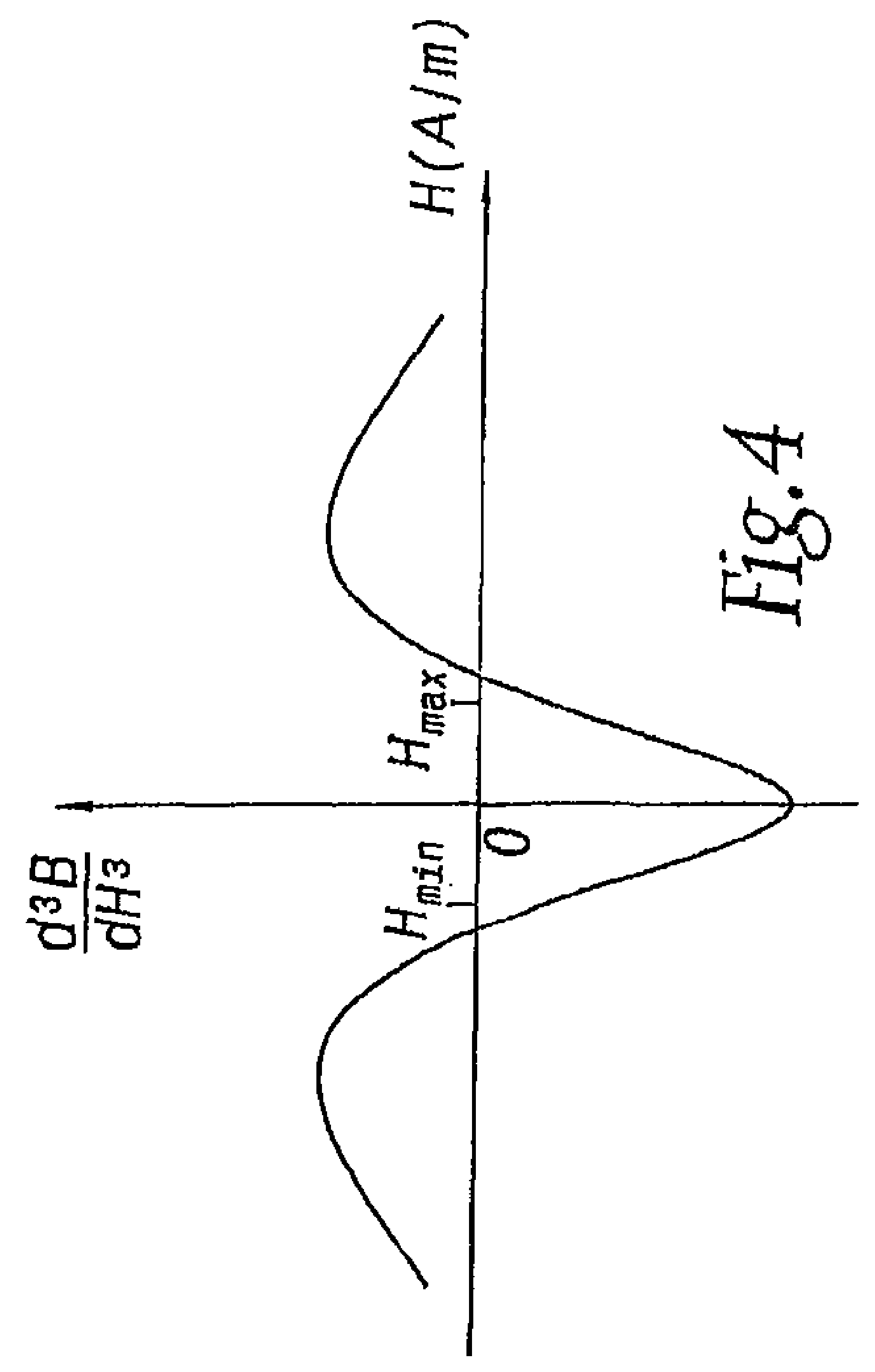


Fig.4

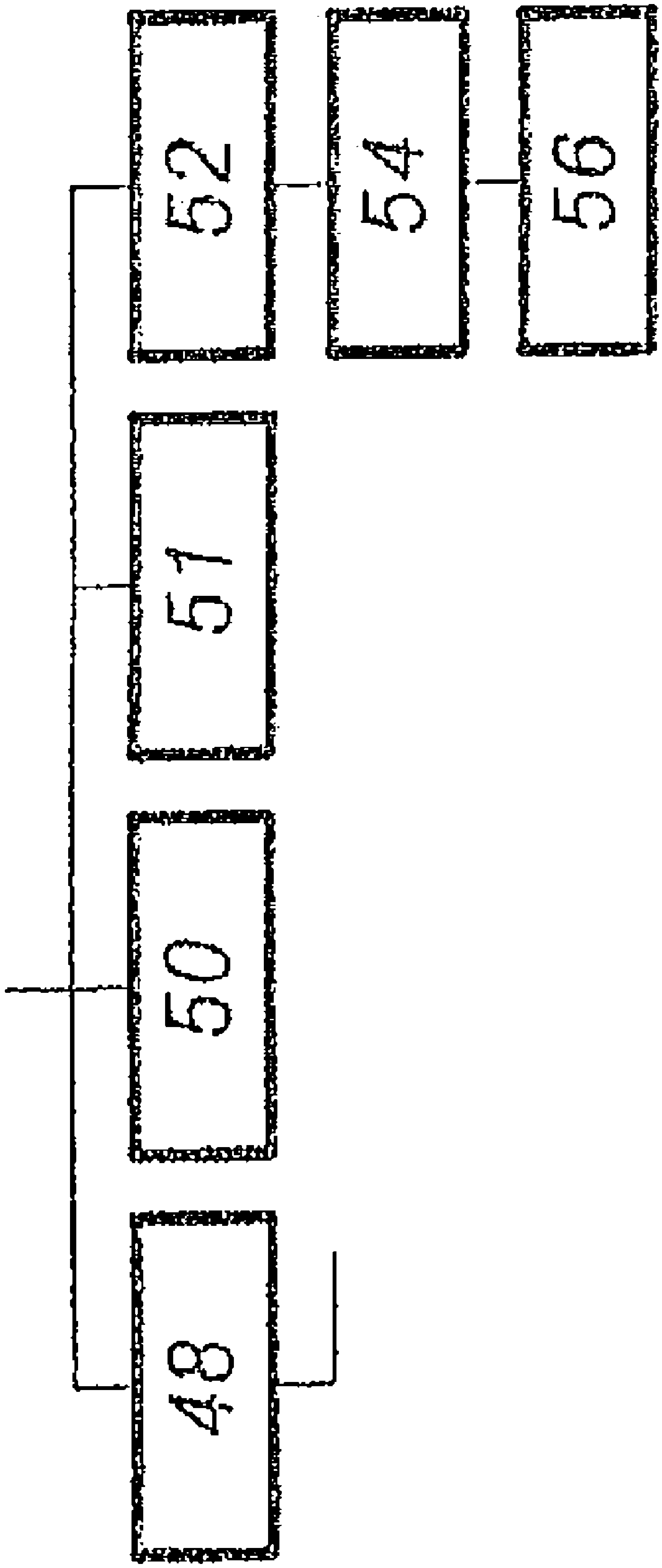


Fig. 5

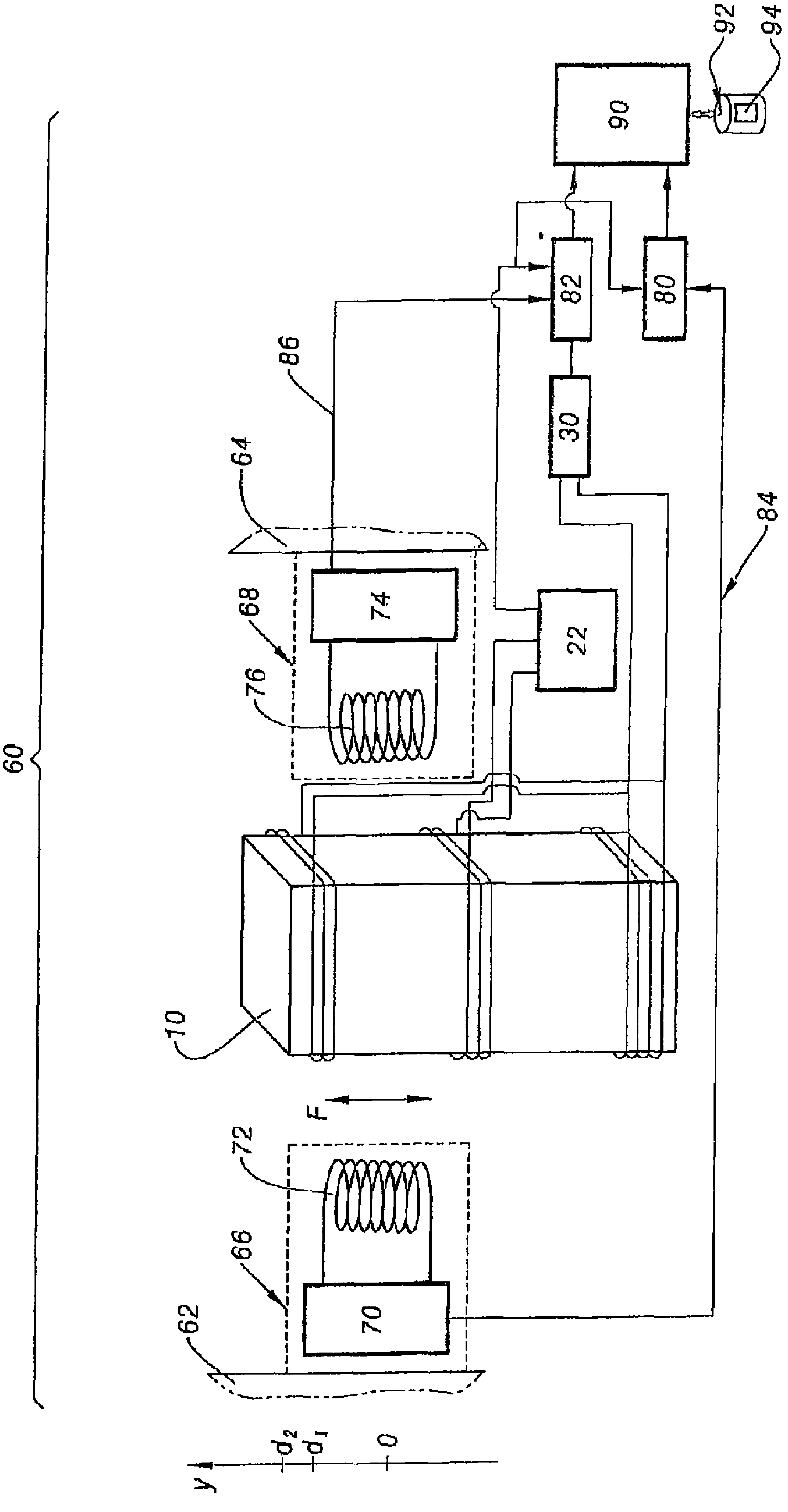
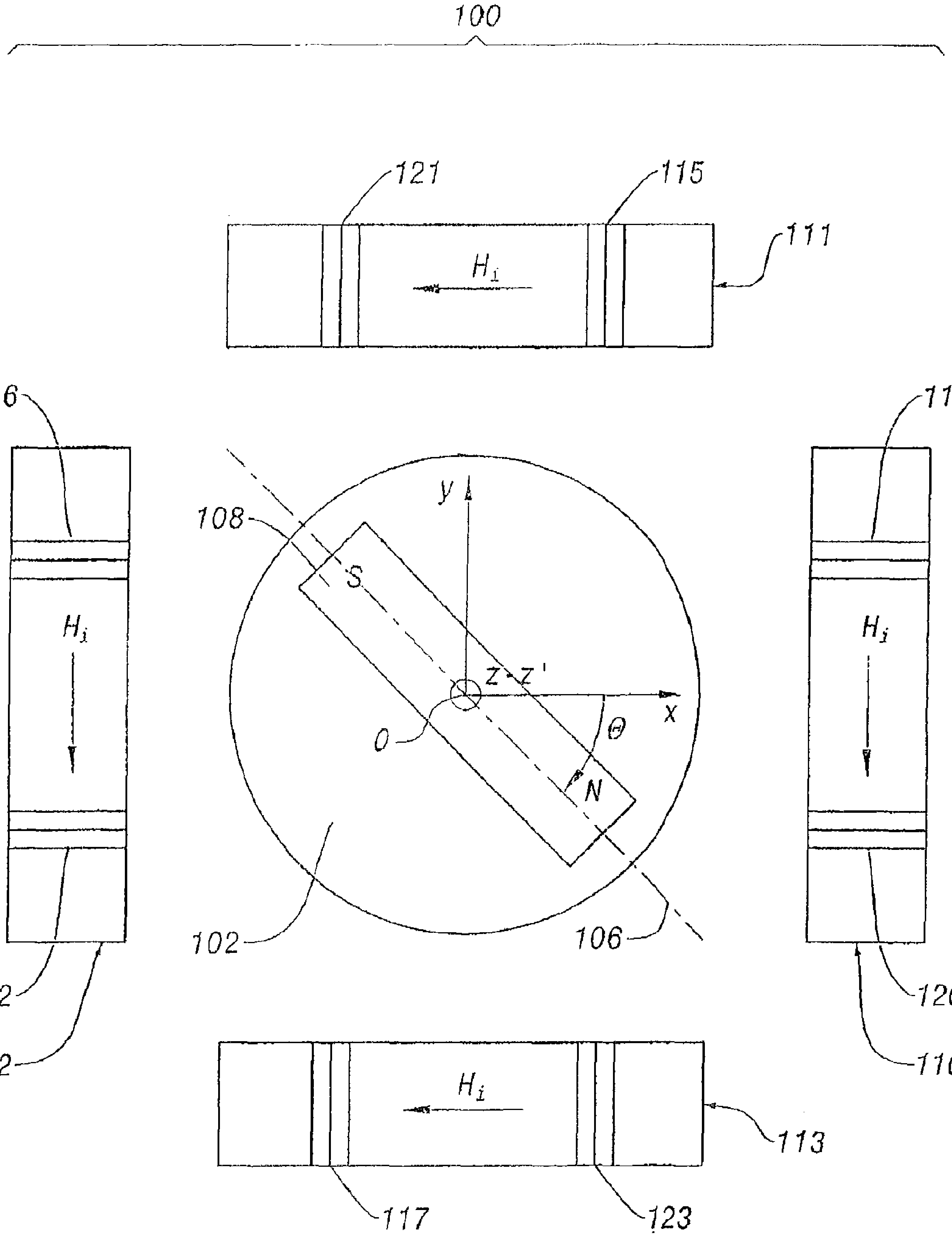


Fig. 6


100
121
115
111
H_i
116
114
108
y
S
z-z'
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N
H_i
H_i
102
106
122
120
112
110
H_i
113
117
123

Fig. 7

DEVICE AND METHOD FOR MEASURING THE POSITION OF A MOBILE PART

The present invention relates to a device and to a method for measuring the position of a moving part.

There exist devices for measuring the position of a first moving part which comprise:

- at least a first generator for generating a first magnetic field to be measured, this first generator being fastened to the first moving part;
- at least one magnetic core capable of modulating the amplitude of an excitation magnetic field as a function of the amplitude of the first magnetic field to be measured, this magnetic core having a magnetic induction cycle as a function of the magnetic field with no hysteresis within an operating range $[H_{min}; H_{max}]$; and
- an electronic computer capable of determining the position of the first moving part relative to the magnetic core from the amplitude of a magnetic field induced in the magnetic core, this induced magnetic field resulting from the combination of the magnetic field to be measured and the excitation magnetic field.

These devices are particularly useful for measuring the position of a part that is rotating or moving translationally.

To modulate the amplitude of the excitation magnetic field, the core must be highly nonlinear and therefore must have a relative permeability that varies with the magnetic field. For this purpose, the materials conventionally used for producing these cores are soft magnetic alloys.

To control the hysteresis problems, isotropic alloys (for example Mu-Metal®) or anisotropic alloys of the oriented nanocrystalline strip type are used. Irrespective of the material, an excitation field that will more or less saturate the material is used. Specifically, the saturation of the magnetic material creates a significant point of inflection in the B(H) magnetic cycle of these materials. This point of inflection is the nonlinearity used to modulate the magnetic field. More precisely, the presence of an external field to be measured will increase the saturation and thus generate harmonics that will be detected. It may also be said that the field to be measured is used to modulate the excitation field.

When the material is saturated, the relative permeability suddenly drops and the core then loses its flux-concentrating capability, thereby lowering the sensitivity of the measurement device.

The aim of the invention is to remedy this drawback by proposing a device for measuring the position of a part in which it is not necessary to saturate the magnetic core.

Therefore one subject of the invention is a measurement device in which the magnetic cycle of the magnetic core is characterized in that the absolute value of the third derivative of the magnetic induction with respect to the magnetic field is a maximum for a zero magnetic field.

It has been discovered that magnetic cores having the above magnetic cycle property exhibit a nonlinearity around the zero magnetic field which is large enough to allow the amplitude of the excitation magnetic field to be modulated by the amplitude of the magnetic field to be measured without it being necessary for this to saturate the magnetic core.

The embodiments of this device may comprise one or more of the following features:

- an electronic circuit capable of generating the excitation magnetic field and/or a feedback magnetic field suitable for permanently keeping the amplitude of the induced magnetic field within the operating range $[H_{min}; H_{max}]$ located around zero, the magnetic core never being saturated within the operating range;

- the magnetic core is a superparamagnetic core;
- the superparamagnetic core is formed from a solid matrix in which superparamagnetic particles are dispersed so as to be spaced apart from one another sufficiently for the core to be superparamagnetic;
- the superparamagnetic particles represent at least 5% of the volume of the matrix into which they are incorporated;
- the device comprises a second generator, for generating a second magnetic field to be measured, this second generator being fastened to a second moving part, the second magnetic field having a power spectrum having at least one power peak at a different frequency from the frequencies for which the power spectrum of the first magnetic field has power peaks; the same magnetic core is also capable of simultaneously modulating the amplitude of the excitation magnetic field as a function of the amplitude of the first and second magnetic fields to be measured; and the electronic circuit is capable of:
- determining the position of the first moving part relative to the core from the amplitude of the magnetic field induced in the magnetic core and from the first field generated during the measurement interval and
- determining the position of the second moving part relative to the core from the amplitude of the same magnetic field induced in the magnetic core and from the second field generated during the same measurement interval,

the magnetic field induced in the magnetic core resulting from the combination of the first and second magnetic fields to be measured and the excitation magnetic field;

- at least one of the power spectra of the excitation magnetic field or of the power spectrum of the magnetic field to be measured has a dominant power peak for a frequency F_0 and in which an electronic circuit capable of measuring an amplitude of the magnetic field to be measured comprises:
- at least one transducer suitable for converting the magnetic field induced inside the core to a measurement signal; and
- an amplitude demodulator suitable for extracting the amplitude of a harmonic of the measurement signal at a frequency NF_0, N being an integer greater than or equal to two;
- N is equal to two; and
- the first generator, fastened to the moving part, generates a DC magnetic field having a positive polarity and a negative polarity and the device includes a third generator, for generating a DC magnetic field to be measured, this third generator being fastened to the same moving part and having a positive polarity and a negative polarity, either the positive polarity or the negative polarity of the third generator being placed opposite the polarity of the same sign of the first generator.

These embodiments of the magnetic field sensor also have the following advantages:

- the fact of preventing saturation to the magnetic core ensures that the core always fulfils the flux-concentrating function and enables the transducer to operate in its linear response zone;
- the magnetic properties of a superparamagnetic core are highly nonlinear, although not exhibiting hysteresis, even when the magnetic field is very much lower than the saturation field;
- introducing more than 5 vol % of superparamagnetic particles into the matrix improves the magnetic properties of the core, thereby improving the performance of the device;

- by simultaneously using two generators, for generating fields to be measured, which are fastened to different parts producing different magnetic fields to be measured, it is possible for the position of these two parts to be measured simultaneously using the same magnetic core;
- by measuring the amplitude of a harmonic of frequency $2F_0$ or higher, it is possible to increase the sensitivity of the device while circumventing any interference with the excitation magnetic field;
- using the amplitude of the harmonic of frequency $2F_0$ simplifies the construction of the device, since the amplitude of this harmonic is directly proportional to the amplitude of the field to be measured; and
- the use of a first and a third generator fastened to the moving part, the poles of the same sign of said generators being placed facing one another, linearizes the variations of the amplitude of the magnetic field to be measured as a function of the position of the moving part, which in the end increases the sensitivity of the device.

Another subject of the invention is a method of measuring the position of at least one moving part, this method comprising:

- the generation of a first magnetic field to be measured by means of a field generator fastened to the first moving part;
- the provision of at least one magnetic core capable of modulating the amplitude of an excitation magnetic field as a function of the amplitude of the first magnetic field to be measured, this magnetic core having a magnetic induction cycle as a function of the magnetic field with no hysteresis within an operating range $[H_{min}; H_{max}]$; and
- the determination of the position of the first moving part relative to the magnetic core from the amplitude of a magnetic field induced in the magnetic core, this induced magnetic field resulting from the combination of the first magnetic field to be measured and the excitation magnetic field,

in which the magnetic cycle of the magnetic core is characterized in that the absolute value of the third derivative of the magnetic induction with respect to the magnetic field is a maximum for a zero magnetic field.

The invention will be better understood on reading the following description, given solely by way of nonlimiting example and with reference to the drawings in which:

FIG. **1** is a schematic illustration of the architecture of a device for measuring the position of a moving part;

FIG. **2** is a graph showing the variation of the magnetic induction ($\vec{B}$) as a function of the induced magnetic field ($\vec{H}$) in a magnetic core of the device of FIG. **1**;

FIG. **3** is a graph showing the variation of the second derivative of the magnetic induction ($\vec{B}$) as a function of the induced magnetic field ($\vec{H}$) in the core of FIG. **1**;

FIG. **4** is a graph showing the variation of the third derivative of the magnetic induction ($\vec{B}$) as a function of the induced magnetic field ($\vec{H}$) in the core of the device of FIG. **1**;

FIG. **5** is a block diagram of a method of measuring the position of a moving part using the device of FIG. **1**;

FIG. **6** is a schematic illustration of the architecture of a device for simultaneously measuring the position of two moving parts; and

FIG. **7** is a schematic illustration of the architecture of a device for measuring the angular position of a rotationally mounted part.

FIG. **1** shows a device **2** for measuring the position of a moving part **4**.

Here, part **4** can move only translationally along a vertical axis Y between two extreme positions d_{min} and d_{max}. The position of the part **4** along the Y axis is indicated by a distance d relative to an origin O.

The device **2** comprises a sensor **6** for detecting a magnetic field H_m to be measured and a generator **8** for generating the magnetic field H_m.

The generator **8** is fixed to the part **4** without any degree of freedom.

The generator **8** is placed opposite the sensor **6** so that the magnetic field H_m generated can be measured by the sensor **6** irrespective of the position of the part **4** between d_{min} and d_{max}. For example, here the generator **8** is a magnet in which the North pole and the South pole of the magnet are aligned along the Y axis.

The height of the magnet along the Y direction is denoted by L_a.

The sensor **6** is equipped with a magnetic core **10** and with an electronic circuit **12** connected to the core **10**. Preferably, the core **10** is a superparamagnetic core.

A superparamagnetic core exhibits a B(H) magnetic cycle, a typical example of which is shown in the graph of FIG. **2**. In FIG. **2**, the magnetic field H in amps per meter is plotted on the x-axis and the magnetic induction B in tesla is plotted on the y-axis.

FIG. **3** shows the variation of the second derivative of the magnetic induction B as a function of the magnetic field H. This second derivative has a virtually linear and highly inclined slope **23** (bounded by the ellipse). This slope **23** is centered on the zero value of the magnetic field H and lies between the bounds H_{min} and H_{max}. Here the bounds H_{min} and H_{max} define the operating range of the sensor **6**. Between the bounds H_{min} and H_{max}, the relative permittivity μ_r of the core is strictly greater than 1, so that the core **10** is never saturated between these bounds.

FIG. **4** shows the variation of the third derivative of the magnetic induction B as a function of the magnetic field H. The absolute value of this third derivative is a maximum when the magnetic field is zero. This extremum when the magnetic field is zero corresponds to the steep slope **23**.

A superparamagnetic material is characterized by the fact that:

1) it has no magnetic remanence, so that the magnetic induction B is zero or virtually zero when the magnetic field H is zero;
2) it exhibits no hysteresis, so that the magnetization curve is coincident with the demagnetization curve in the B(H) magnetic cycle;
3) the relative permeability varies continuously and nonlinearly with the magnetic field;
4) the B(H) magnetic cycle has the same form and the same properties irrespective of the direction of the magnetic field H; and
5) the absolute value of the third derivative of the magnetic induction B with respect to the magnetic field H has a maximum when the magnetic field H is zero.

Feature 2) differentiates superparamagnetic materials from soft magnetic alloys, such as mu-metal®.

Feature 4) differentiates superparamagnetic materials from an oriented nanocrystalline strip, since the latter exhibits a B(H) magnetic cycle with no hysteresis and no magnetic remanence only for a single specified direction of the magnetic field H. Consequently, the orientation of the superparamagnetic core relative to the magnetic field to be measured does not matter, whereas this is not so in the case when the core is made from an oriented nanocrystalline strip.

Feature 5) derives from the fact that the B(H) magnetic cycle is highly nonlinear around the zero magnetic field. It also follows that the slope **23** is steeply inclined. Thus, a weak variation of the magnetic field H results in a large variation of the second derivative of the magnetic induction B and also in a large variation of the amplitude of the even harmonics in the measured signal. The even harmonics are defined as those whose frequency is an integer multiple N of the frequency of the excitation of the magnetic field, N being an even number. This explains why the sensor **6** is very sensitive to variations of the magnetic field to be measured around the zero magnetic field.

In addition, the slope **23** is linear or practically linear over the operating range of the sensor **6**, so that the conversion of the measured signal to a magnetic field is simplified.

The superparamagnetic material used here to produce the core **10** comprises a solid matrix through the thickness of which superparamagnetic particles are incorporated. These superparamagnetic particles are for example ferromagnetic particles of which the largest dimension is small enough for them to be taken individually, to exhibit a B(H) magnetic cycle having the same properties as that shown in FIG. **3**. Typically, the largest dimension of the ferromagnetic particles is chosen to be less than 100 nanometers and most often less than 20 nanometers. This largest dimension of the ferromagnetic particles below which they become superparamagnetic depends on the ferromagnetic material used. Superparamagnetism and superparamagnetic particles are described in the following literature reference: E. du Trémolet de Lacheisserie et al., "Magnetisme [*Magnetism*]", Volume 1, Presses Universitaire de Grenoble, 1999.

Iron oxides are the preferred superparamagnetic particles. For completeness, it should be pointed out that the superparamagnetic particles may be chosen from iron oxides and mixed oxides of iron and another metal, especially one chosen from Mn, Ni, Zn, Bi, Cu and Co. The iron oxides Fe_3O_4 and Fe_2O_3 are preferably used. It is also possible to use perovskites having superparamagnetic properties, particularly iron-based perovskites, superparamagnetic nickel oxides and cobalt oxides or mixed nickel cobalt oxides, or else superparamagnetic metal alloys, e.g. of the FeNi and CoNi type, particularly $Fe_{20}Ni_{80}$.

The solid matrix is chosen so as not to disturb the magnetic properties of the superparamagnetic particles. For example, the solid matrix is only diamagnetic.

Furthermore, it should be noted that the term "solid" denotes here also matrices made of reversibly elastically deformable materials, such as elastomers.

Various materials that can be used as a solid matrix within the context of the invention may be used. Preferably, the matrix is a plastic, especially one chosen from thermosets (e.g. phenoplasts, aminoplasts, epoxy resins, unsaturated polyesters, crosslinked polyurethanes and alkyds) and thermoplastics (e.g. polyvinyl polymers, such as polyvinyl chlorides, and polyvinyl acetates, polyvinyl alcohols, polystyrenes and copolymers, acrylic polymers, polyolefins, cellulose derivatives and polyamides), or else special polymers (e.g. fluoropolymers, silicones, synthetic rubbers, saturated polyesters, linear polyurethanes, polycarbonates, polyacetales, polyphenylene oxides, polysulfones, polyethersulfones, polyphenylene sulfides, and polyimides). The elastomers may in particular be of the silicone or synthetic rubber type.

The material constituting the matrix may be chosen depending on the final application, and in particular on the usage conditions. Thus, in the automotive industry, matrices resistant to standard operating temperatures, especially temperatures ranging from −30° C. to +150° C., are recommended. In the aeronautical field, the typical temperature range that the matrix must withstand is from −40° C. to +100° C.

At the material preparation stage, the superparamagnetic particles may be incorporated in powder form into the material intended to form the matrix or into a fraction or portion of this material. Said particles may also be supplied already dispersed in a medium, which will be mixed with the material intended to form the matrix or with a fraction or portion of this material. In all cases, the mixing must be sufficient to obtain in the end a suitable dispersion of the particles throughout the matrix.

The material may be produced directly in bulk form or may be obtained from beads, granules or the like of the matrix that includes the superparamagnetic particles, these beads, granules or the like then being agglomerated under pressure, sintered, melted or subjected to any other suitable process.

Thus, the material may be produced by mixing the constituent(s) of the matrix with a suspension of superparamagnetic particles in an organic phase which is miscible with the constituent(s) of the matrix, followed by polymerization. The organic phase containing the superparamagnetic particles may be formed from or comprise an organic solvent, or else may be formed from or comprise one or more constituents of the matrix. To give an example, the material is produced by emulsion polymerization, e.g. the superparamagnetic particles are dispersed in an organic phase containing the constituent(s) of the matrix, then the dispersion obtained is mixed with all or part of an aqueous solution formed from water and at least one emulsifier, and then the mixture is homogenized and finally polymerized. To give an illustration, the emulsion polymerization process described in FR-A-2 480 764 may be employed.

To facilitate manufacture of the core **10**, the matrix here is made of a thermoplastic or thermosetting material.

The distribution of the superparamagnetic particles within the matrix is such that the distances between superparamagnetic particles are sufficient for the macroscopic core formed by this matrix and the superparamagnetic particles to have the same magnetic properties as the particles that form it.

Preferably, the superparamagnetic particles are uniformly distributed within the matrix, so as to have a uniform spatial distribution of the magnetic properties.

The superparamagnetic particles represent a percentage P of the total volume of the superparamagnetic core. Typically, the percentage P is chosen to be greater than 2.5%, preferably greater than 5% or even 15%. Furthermore, although this runs the risk of complicating the electronics used to determine the position of the moving part, the percentage P may be chosen to be for example strictly less than 5%, as this reduces the cost of the core **10**.

There is a threshold L for the percentage P above which the core formed by this matrix and these superparamagnetic particles loses its superparamagnetic properties, since the distances between superparamagnetic particles are too short, so that the superparamagnetic particles are magnetically coupled to one another and then behave as a ferromagnetic particle, the largest dimension of which exceeds the threshold above which the superparamagnetic properties disappear.

The percentage P is also chosen to be as close as possible to this limit L, without exceeding it. For example, the percentage P is chosen within the range defined by the following relationship:

$$L-10\% \leqq P \leqq L-1\%.$$

The higher the percentage P, the greater the capability of the core **10** to concentrate the flux to be measured, thereby improving the performance of the sensor **6**.

The relative permeability μ_r of the core **10** is preferably strictly greater than 1 so as to concentrate the magnetic flux. Here, the maximum value μ_{max} of the relative permeability of the core **10** is obtained for a zero value of the induced magnetic field in the core **10**. For example, μ_{max} is greater than 1.5.

The circuit **12** is capable of exciting the core **10** by means of an excitation magnetic field H_{ex} and of measuring the induced magnetic field H_i in the core **10** in response to this excitation.

The field H_{ex} is an AC magnetic field, the frequency F_0 of which is at least twice that of the magnetic field to be measured. Typically, the frequency of the magnetic field H_{ex} is greater than 100 Hz and preferably greater than 1000 Hz.

The circuit **12** includes an adjustable source for creating the field H_{ex}. This source is for example formed from an excitation coil **20** supplied with AC current of frequency F_0 by a controllable power supply **22**.

The coil **20** is wound around the core **10** so that the field H_{ex} is vertical.

The circuit **12** also includes at least one transducer suitable for converting the induced magnetic field H_i inside the core **10** to an electrical measurement signal, such as a measurable current or voltage. For this purpose, the or each of these transducers has a surface sensitive to the field H_i.

The circuit **12** here comprises two transducers **26** and **28** sensitive to the fields H_i within the core.

For example, the transducers **26** and **28** are measurement coils wound around the core **10** in opposite directions to each other. These transducers **26** and **28** are each placed at a respective end of the core **10**. The coil **20** is placed at mid-distance between the transducers **26** and **28**.

The transducers **26** and **28** are differentially connected to the input of a passive filter **30**. Thus, in the absence of a magnetic field to be measured, the electrical signal at the input of the filter **30** is zero. Such a differential arrangement of the transducers **26** and **28** enables the sensitivity of the sensor **6** to be increased.

The length of the core **10** in the Y direction is denoted by L_n. The length of the transducer **26** or **28** in the Y direction is denoted by L_b. In general, in the device **2**, the lengths L_a, L_n and L_b must satisfy the following relationship:

$$L_b < L_a < 10L_n.$$

Here, L_a is less than L_n.

The filter **30** is used for prefiltering, so as to remove the harmonics of no interest for the rest of the processing from the electrical measurement signal.

The output of the filter **30** is connected to the input of an amplitude demodulator **32** suitable for extracting the amplitude of one or more harmonics of the measurement signal. Here, the demodulator **32** extracts the amplitudes of the harmonics having frequencies that are integer multiples of F_0, where F_0 is the frequency of the excitation field. Preferably, if the amplitude of a single harmonic is measured, the frequency of this harmonic is NF_0, where N is an even number so as to make the signal processing easier. For example, here N is equal to 2.

The demodulator **32** is, for example, a synchronous demodulator connected to the power supply **22** so as to be phase-synchronized with said supply.

The circuit **12** also includes a field feedback for making the sensor **6** more robust with respect to temperature variations and to increase its linearity range.

The field feedback is also used here to keep the amplitude of the field H_i permanently within the operating range $[H_{min}; H_{max}]$ located around zero, and preferably centered around the zero value. The operating range $[H_{min}; H_{max}]$ is shown in FIGS. **2** to **4**.

For this purpose, the circuit **12** is equipped with a regulator **36**, one input of which is connected to an output of the demodulator **32** and the outputs of which are connected to a field feedback coil **40**. The regulator **36** is capable of controlling the coil **40** in such a way that the latter creates a feedback magnetic field H_c suitable for nullifying the magnetic field H_m to be measured.

For this purpose, the coil **40** is wound around the core **10**. The coil **40** is located here at mid-distance between the transducers **26** and **28**.

The current flowing in the coil **40** is representative of the amplitude of the magnetic field to be measured.

One of the outputs of the regulator **36** is connected to a computer **44** suitable for calculating the distance d from the amplitude A of the magnetic field H_m.

For this purpose, the computer **44** is connected to a memory **46** containing a table **48** of standard values. The table **48** contains, for example, the values of the amplitude A of the magnetic field H_m that are measured for known positions of the moving part **4**.

The operation of the device **2** will now be described in conjunction with the method shown in FIG. **5**.

During step **48**, the generator **8** generates the magnetic field H_m to be measured. The field lines of the magnetic field H_m are concentrated within the core **10**. The amplitude of the field H_m in the core **10** depends on the distance separating the generator **8** from the core **10** and is therefore a function of the distance d.

In parallel, during step **50**, the coil **20** creates the field H_{ex} inside the core **10**. Also in parallel, during step **51**, the coil **40** creates the magnetic field H_c.

The magnetic field H_i which is induced inside the core **10** and to which the transducers **26** and **28** are sensitive is therefore the result of the vector sum of the fields H_m, H_{ex} and H_c.

During steps **50** and **51**, the circuit **12** generates the fields H_{ex} and H_c so that the amplitude of the induced magnetic field H_i is kept within the $[H_{min}; H_{max}]$ range.

The induced magnetic field is converted in step **52** to a current by the transducers **26** and **28**.

All the following steps for processing the current produced by the transducers **26** and **28**, so as to obtain a magnetic field amplitude H_m, are collected in step **54**.

The filter **30** filters the difference between the currents generated by the transducers **26** and **28** so as to obtain a filtered signal. The demodulator **32** extracts the amplitude of the harmonic of frequency NF_0 from the filtered signal. The appearance of this harmonic of frequency NF_0 is linked to the nonlinearity of the B(H) magnetic cycle of the core **10** and therefore to the nonlinear variations of the relative permeability of the core **10**. More precisely, the deformations of the field H_{ex} due to these nonlinearities vary with the amplitude of the field H_m. These deformations of the field H_{ex} result from the presence of harmonics at multiples of F_0 in the induced magnetic field H_i measured by the transducers **26** and **28**.

This amplitude is used by the regulator **36** to control the coil **40** so as to generate the field H_c of opposite direction and opposite amplitude to the field H_m.

The feedback signal generated by the regulator **36** is therefore representative of the amplitude A of the field H_m.

During step **56**, the computer **44** establishes the actual distance d from the amplitude A of the field H_m. For this purpose, during step **56**, the computer uses the reference values recorded in the table **48**.

FIG. **6** shows a device **60** for measuring the simultaneous position of two moving parts **62** and **64** along a vertical axis Y. The positions of the parts **62** and **64** are identified by distances d_1 and d_2 respectively relative to an origin O on the Y axis.

Generators **66** and **68** are fixed without any degree of freedom to the parts **62** and **64** respectively. The generators **66** and **68** generate fields to be measured, H_{m1} and H_{m2} respectively, parallel to the Y axis.

The generator **66** here is formed from an AC current source **70** supplying a coil **72** so as to generate the magnetic field H_{m1} at the frequency f_1.

Similarly, the generator **68** is formed from an AC current source **74** connected to a coil **76** which generates the magnetic field H_{m2} to be measured at the frequency f_2.

The power spectrum of the magnetic field H_{m2} differs from the power spectrum of the field H_{m1} at least by the position of a power peak. For example, here the power spectrum of the fields H_{m1} and H_{m2} each have a single power peak at frequencies f_1 and f_2 respectively, which are different.

The device **60** also includes a magnetic field sensor for detecting the magnetic field to be measured, this being similar to the sensor **6** except for the fact that the synchronous demodulator **32** is replaced by two synchronous demodulators **80** and **82**. To simplify FIG. **6**, the components for producing a field feedback have not been shown.

The synchronous demodulator **80** is connected by a link **84** to the generator **66** so as to be phase-synchronized with this generator. The demodulator **80** is configured so as to extract the amplitude of the harmonic of frequency $n_1F_0+m_1f_1$ from the measurement signal delivered by the filter **30**, where n_1 and m_1 are non zero integers. Preferably, n_1 is equal to 2 and m_1 is equal to ±1.

Similarly, the demodulator **82** is connected via a link **86** to the generator **68** so as to be phase-synchronized with this generator. The generator **82** is configured to extract the amplitude of the harmonic of frequency $n_2F_0+m_2f_2$ from the measurement signal, where n_2 and m_2 are non zero integers. Preferably, n_2 is equal to 2 and m_2 is equal to **±1**.

The amplitudes A_1 and A_2 extracted by the demodulators **80** and **82** are uniquely proportional to the distances d_1 and d_2 respectively. The amplitudes A_1 and A_2 are sent to a computer **90** connected to a memory **92** containing a table **94** of reference values. The table **94** contains values of the amplitudes extracted by the demodulators **80** and **82** for known distances d_1 and d_2.

The computer **90** is capable of establishing the distances d_1 and d_2 from the values contained in the table **94**.

Preferably, the frequency F_0 of the magnetic field H_{ex} is more than ten times higher than the frequency f_1 or f_2.

The operation of the device **60** derives from the operation described in respect of the device **2**. However, the device **60** is capable of simultaneously measuring the position of the parts **62** and **64** using a common core **10**. This is because the harmonics of frequency $n_1F_0+m_1f_1$ are created only by the generator **66**, whereas the harmonics of frequency $n_2F_0+m_2f_2$ are only created by the generator **68**.

FIG. **7** shows a device **100** for measuring the angular position θ of a moving part **102**. The part **102** is mounted so as to rotate about an axis Z-Z' perpendicular to the plane of the sheet. The angle θ is defined between:

- a horizontal direction X perpendicular to the Z-Z' axis and intersecting the Z-Z' axis at a point O; and
- a fixed axis **106** of the part **102** perpendicular to the Z-Z' axis and passing through the point O.

The device **100** comprises a magnet **108** fixed with no degree of freedom to one end of the part **102**. The Z-Z' axis passes through the center of this magnet **108** and the North and South poles of this magnet are located to the right and to the left of the Z-Z' axis respectively.

The device **100** also includes four cores **110** to **113** made of superparamagnetic material, these being based around the periphery of the part **102**.

The cores **110** and **112** lie in the plane defined by the X axis and a Y axis perpendicular to the X and Z-Z' axes and passing through the point O. In this plane, the cores **110** and **112** are placed in diametrically opposed positions relative to the point O. Here, the cores **110** and **112** are placed on the X axis.

Similarly, the cores **111** and **113** lie in the plane defined by the X and Y axes and are placed so as to be diametrically opposed relative to the point O. Here, the cores **111** and **113** are placed on the Y axis.

Each of these cores has an excitation coil, **114** to **117** respectively, suitable for creating an AC excitation magnetic field H_{ex} in each of these cores at the frequency F_0.

Each of these cores **110** to **113** also includes a transducer, **120** to **123** respectively, suitable for measuring the magnetic field H_i induced in each of these cores.

The transducers **120** and **122** are connected differentially to the input of a filter and then of a first synchronous demodulator suitable for extracting the amplitude A_1 of the harmonic of frequency NF_0, where N is an integer greater than or equal to 2.

The transducers **121** and **123** are also connected differentially to the input of another filter and to a second synchronous demodulator suitable for extracting the amplitude A_2 of the harmonic of frequency NF_0. The amplitudes A_1 and A_2 are each proportional to the angle θ to within ±180°. Therefore, by combining the amplitudes A_1 and A_2 it is possible to obtain a measurement of the angle θ with an uncertainty strictly less than 180°.

The operation of the device **100** derives from that of the device **2**.

Many other embodiments are possible. For example, in each of the embodiments in which the generator is a magnet, this may be replaced with a coil producing a constant DC field or with a coil producing a periodic field, the frequency spectrum of which is known.

Although the various embodiments have been described in the particular case in which two differentially connected transducers are used, it is possible to omit one of these two transducers and to work only with a single transducer, this being in particular the case if, for example, there is superposed on top of the magnet **8** of the device **2** an identical magnet, but placed head-to-tail with the latter, i.e. the polarities with respect to the magnet **8** and the added magnet are the same. This makes it possible to linearize the variations of the magnetic field to be measured as a function of the distance d in the vicinity of a zero magnetic field to be measured. Instead of magnets, it may also be possible to use two DC magnetic field generators placed in opposite directions with respect to each other.

A magnetically conductive material may be interposed between the core and the generator fixed to the moving part.

It is also possible to determine the position of the moving part from the amplitude of the fundamental of the measurement signal. To do this, a synchronous demodulator or a measurement of the variation of the inductance may be used. This corresponds to the case in which N is equal to 1 in the device **100**.

The excitation magnetic field H_{ex} is not necessarily a sinusoidal field. As a variant, this excitation field has any waveform. For example, the waveform is rectangular, triangular or of another shape.

Similarly, the waveform of the magnetic field to be measured is not necessarily sinusoidal or constant. For example, a known pseudorandom signal may be used. In the latter case, the synchronous demodulator is replaced with an amplitude demodulator suitable for extracting the amplitude of the magnetic field induced in the core in response to the field H_m from the measurement signal. For this purpose, the demodulator uses for example the known pseudorandom signal.

What has been described with regard to FIG. **7**, i.e. the use of transducers connected differentially but wound around separate cores, may be applied to the other embodiments described here.

The excitation and measurement coils may coincide. Likewise, the excitation coil and the field feedback coil may also be coincident.

The field feedback may be omitted.

The measurement of harmonics may be reduced to measuring a single harmonic, and in this case it will be preferable to choose an even harmonic, i.e. N=2.

The coils and the transducers may be embedded within the superparamagnetic core using any type of molding or over-molding process.

The superparamagnetic core may be replaced by any core made of a magnetic material (for example a composite of soft magnetic alloys) having curves similar to those shown in FIGS. **2** to **4**.

The superparamagnetic core is used here at the same time as modulator of the excitation magnetic field as a function of the magnetic field to be measured and as magnetic flux concentrator. As a variant, the superparamagnetic core may be used in a magnetic field sensor only as modulator.

The device **60** has been described in the particular case in which the same core **10** is used for simultaneously measuring the position of two moving parts **62** and **64**. The teaching given with regard to the device **60** may be generalized to the simultaneous measurement of the position of more than two moving parts. For this purpose, each moving part will be equipped with its own generator for generating the field to be measured. The various magnetic fields to be measured, generated by each of these generators, have power spectra that differ from one another at least by the position of a power peak.

The invention claimed is:

1. A device for measuring the position of at least a first moving part (**4**; **62**; **64**, **102**), this device comprising:

at least a first generator (**8**; **66**; **108**) for generating a first magnetic field to be measured, this first generator being fastened to the first moving part;

at least one magnetic core providing means for capable of modulating the amplitude of an excitation magnetic field (H_{ex}) as a function of the amplitude of the first magnetic field to be measured, this magnetic core having a magnetic induction cycle as a function of the magnetic field with no hysteresis within an operating range [H_{min}; H_{max}]; and

an electronic computer (**44**) providing means for determining the position of the first moving part relative to the magnetic core from the amplitude of a magnetic field induced in the magnetic core, this induced magnetic field resulting from the combination of the magnetic field to be measured and the excitation magnetic field,

in which the magnetic cycle of the magnetic core (**10**; **110-113**) is characterized in that the absolute value of the third derivative of the magnetic induction with respect to the magnetic field is a maximum for a zero magnetic field.

2. The device as claimed in claim **1**, in which an electronic circuit (**12**) is providing means for generating the excitation magnetic field and/or a feedback magnetic field suitable for permanently keeping the amplitude of the induced magnetic field within the operating range [H_{min}; H_{max}] located around zero, the magnetic core never being saturated within the operating range.

3. The device as claimed in claim **1**, in which the magnetic core (**10**; **110-113**) is a superparamagnetic core.

4. The device as claimed in claim **3**, in which the superparamagnetic core (**10**; **110-113**) is formed from a solid matrix in which superparamagnetic particles are dispersed so as to be spaced apart from one another sufficiently for the core to be superparamagnetic.

5. The device as claimed in claim **4**, in which the superparamagnetic particles represent at least 5% of the volume of the matrix into which they are incorporated.

6. The device as claimed in claim **1**, in which the device comprises:

a second generator (**68**) for generating a second magnetic field to be measured, this second generator being fastened to a second moving part (**64**), the second magnetic field having a power spectrum having at least one power peak at a different frequency from the frequencies for which the power spectrum of the first magnetic field has power peaks;

the same magnetic core (**10**) is also providing means for simultaneously modulating the amplitude of the excitation magnetic field as a function of the amplitude of the first and second magnetic fields to be measured; and

the electronic circuit providing means for:

determining the position of the first moving part (**62**) relative to the core (**10**) from the amplitude of the magnetic field induced in the magnetic core and from the first field (H_{m1}) generated during the measurement interval (T) and

determining the position of the second moving part (**64**) relative to the core (**10**) from the amplitude of the same magnetic field induced in the magnetic core and from the second field (H_{m2}) generated during the same measurement interval (T),

the magnetic field induced in the magnetic core resulting from the combination of the first and second magnetic fields to be measured and the excitation magnetic field.

7. The device as claimed in claim **1**, in which at least one of the power spectra of the excitation magnetic field or the power spectrum of the magnetic field to be measured has a dominant power peak for a frequency F_0 and in which an electronic circuit (**12**) providing means for measuring an amplitude of the magnetic field to be measured comprises:

at least one transducer (**26**, **28**) suitable for converting the magnetic field induced inside the core (**10**) to a measurement signal; and

an amplitude demodulator (**32**; **80**, **82**) suitable for extracting the amplitude of a harmonic of the measurement signal at a frequency NF_0, N being an integer greater than or equal to two.

8. The device as claimed in claim **7**, in which N is equal to two.

9. The device as claimed in claim **1**, in which:

the first generator, fastened to the moving part, generates a DC magnetic field having a positive polarity and a negative polarity; and

the device includes a third generator, for generating a DC magnetic field to be measured, this third generator being fastened to the same moving part and having a positive polarity and a negative polarity, either the positive polarity or the negative polarity of the third generator being placed opposite the polarity of the same sign of the first generator.

10. A method of measuring the position of a first moving part (**4**), this method comprising:

the generation (**48**) of a first magnetic field to be measured by means of a field generator fastened to the first moving part (**4**);

the provision of at least one magnetic core (**10**) providing means for modulating the amplitude of an excitation magnetic field as a function of the amplitude of the first magnetic field to be measured, this magnetic core having a magnetic induction cycle as a function of the magnetic field with no hysteresis within an operating range [H_{min}; H_{max}] ; and

the determination (**56**) of the position of the first moving part (**4**) relative to the magnetic core from the amplitude of a magnetic field induced in the magnetic core (**10**), this induced magnetic field resulting from the combination of the first magnetic field to be measured and the excitation magnetic field,

in which the magnetic cycle of the magnetic core (**10**) is characterized in that the absolute value of the third derivative of the magnetic induction with respect to the magnetic field is a maximum for a zero magnetic field.

11. The device as claimed in claim **2**, in which the magnetic core (**10**; **110**-**113**) is a superparamagnetic core.

12. The device as claimed in claim **2**, in which the device comprises:

a second generator (**68**) for generating a second magnetic field to be measured, this second generator being fastened to a second moving part (**64**), the second magnetic field having a power spectrum having at least one power peak at a different frequency from the frequencies for which the power spectrum of the first magnetic field has power peaks;

the same magnetic core (**10**) is also providing means for simultaneously modulating the amplitude of the excitation magnetic field as a function of the amplitude of the first and second magnetic fields to be measured; and

the electronic circuit is providing means for:

determining the position of the first moving part (**62**) relative to the core (**10**) from the amplitude of the magnetic field induced in the magnetic core and from the first field (H_{m1}) generated during the measurement interval (T) and

determining the position of the second moving part (**64**) relative to the core (**10**) from the amplitude of the same magnetic field induced in the magnetic core and from the second field (H_{m2}) generated during the same measurement interval (T),

the magnetic field induced in the magnetic core resulting from the combination of the first and second magnetic fields to be measured and the excitation magnetic field.

13. The device as claimed in claim **2**, in which at least one of the power spectra of the excitation magnetic field or the power spectrum of the magnetic field to be measured has a dominant power peak for a frequency F_0 and in which an electronic circuit (**12**) providing means for measuring an amplitude of the magnetic field to be measured comprises:

at least one transducer (**26**, **28**) suitable for converting the magnetic field induced inside the core (**10**) to a measurement signal; and

an amplitude demodulator (**32**; **80**, **82**) suitable for extracting the amplitude of a harmonic of the measurement signal at a frequency NF_0, N being an integer greater than or equal to two.

14. The device as claimed in claim **2**, in which N is equal to two.

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